Analysis of the Mechanical Properties of Multicrystalline and Monocrystalline Silicon Wafers Manufactured by Casting Methods

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INTRODUCTION

The era of the *quasi-mono* or *mono-like* based ingots and wafers has arrived. Typical casting processes are now able to be used to produce solar wafers that share some the advantages of the well-known Cz-Si mono crystals and the higher cost-effectiveness of multicrystalline processes.

Quasi-mono materials still need to be thoroughly studied and characterized, as a series of extended defects can be observed when comparing diverse zones in an industrial ingot. In this work, a systematic analysis of the mechanical strength of commercial wafers having different crystal features is presented, including two different batteries of mono-like wafers made from typical casting growth methods, as directional solidification (DSS).

Mono casting (MC)
Monocrystalline 100%

Quasi-mono (QM)
Monocrystalline >90%

DCWafers plus (DCW+)
Monocrystalline >75%

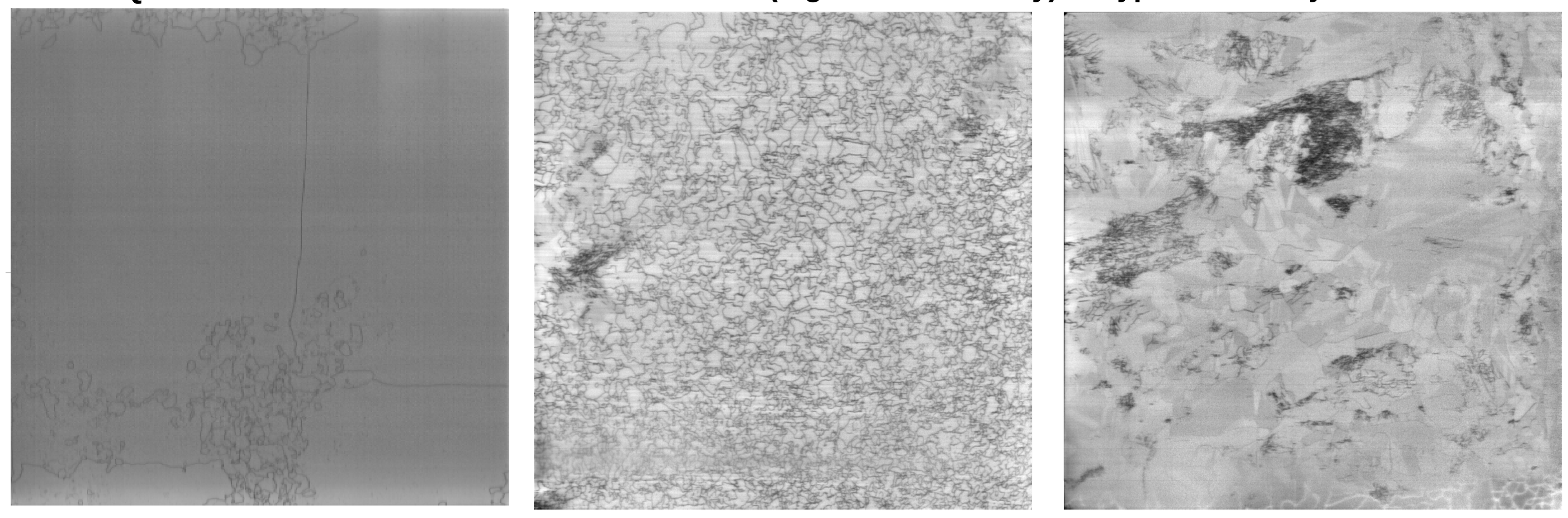
Mc-Si (multi or mono/multi)
Monocrystalline <75%

SAMPLES

Quasi-mono, quasi-mono with a high density of extended defects (dislocations and sub-grain boundaries), multicrystalline wafers were obtained from ingots growth using typical industrial DSS furnaces (450 kg charge) by different approaches. Quasi-mono samples were specially manufactured by a special monocrystaline seed-assisted growth, exhibiting (100) orientation all over the surface.

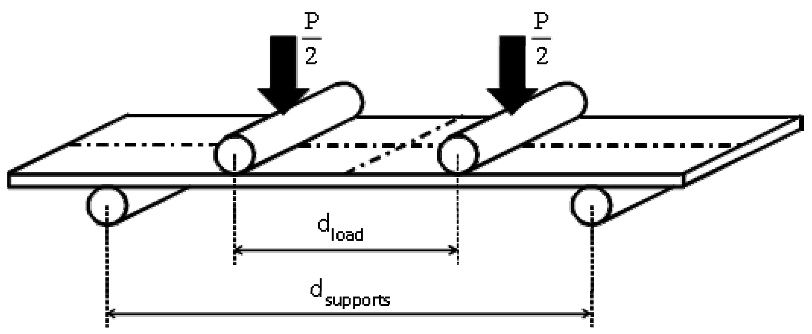
50 samples of each type were selected and measured according to the Four Line Bending Test methodology, in order to compare the different mechanical stability, by measuring the respective fracture stress. The wafer surfaces were chemically etched back (ca. 25 microns thick) to avoid any influence from the subsurface damage resulted from the wire sawing process in the mechanical properties under study (microcracks, saw marks, microinclusions, etc.). So, the intrinsic contribution of the respective crystal features was directly analyzed.

Quasi-mono wafer | **Quasi-mono wafer (high defect density)** | **Typical multicrystalline wafer**

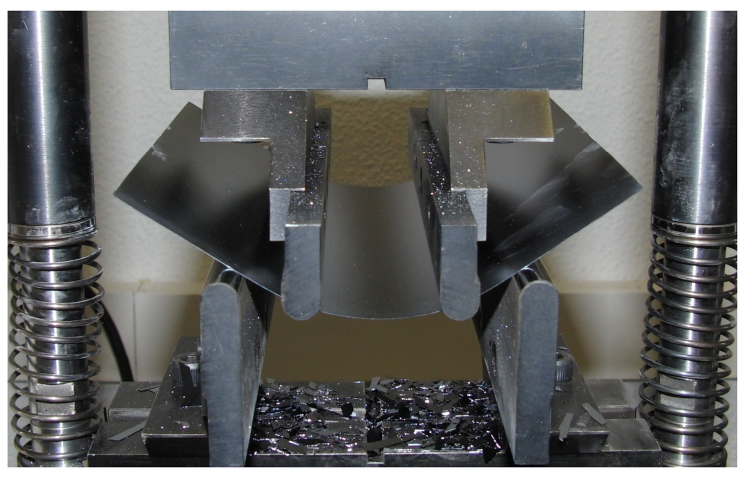


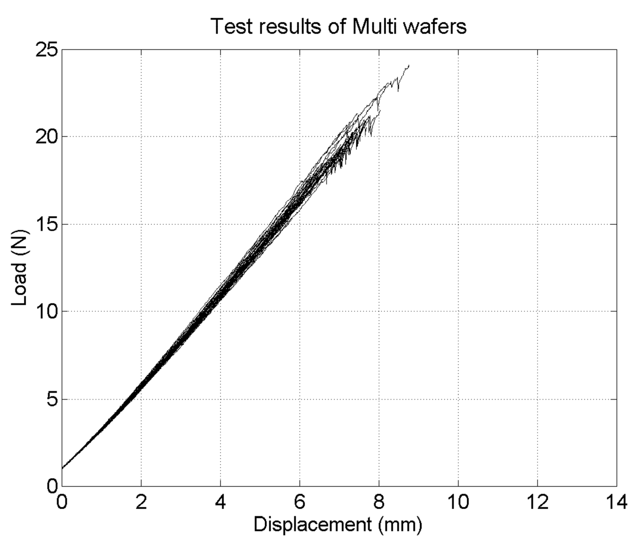
Photoluminiscence (PL) images (156x156 mm wafers) showing different density of extended defects

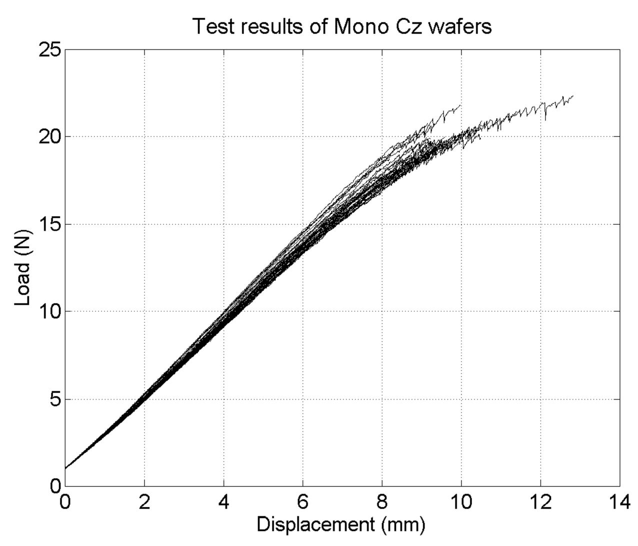
FOUR LINE BENDING TEST

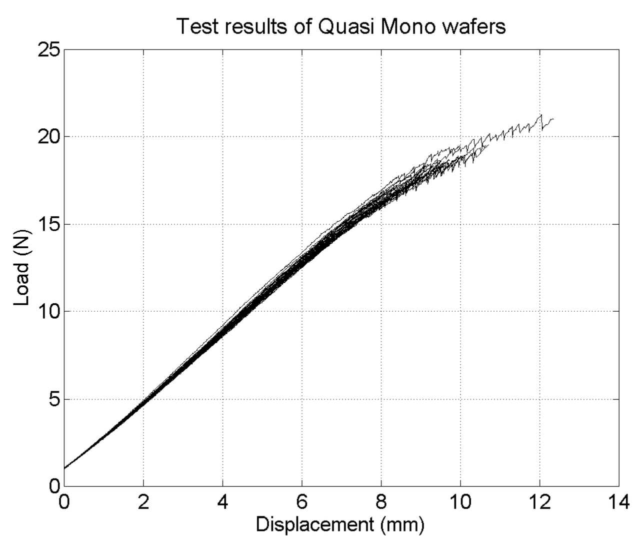


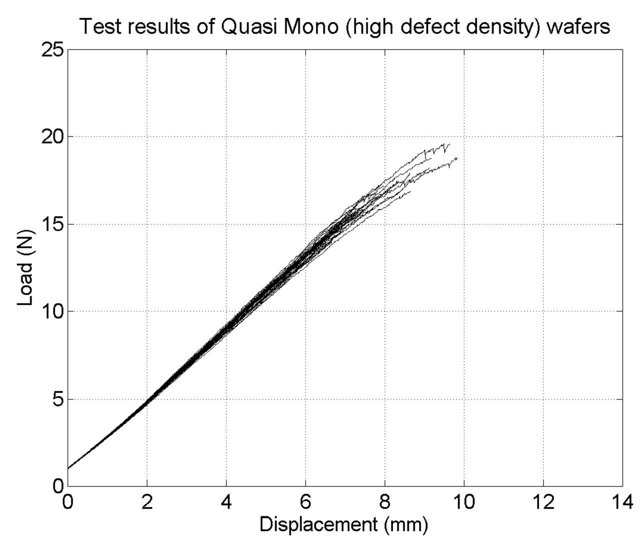
- **Test parameters**
  - **d_{load} = 40 mm**
  - **$d_{supports}$ = 80 mm**
  - **50 samples of each set tested**
  - **156 mm x 156 mm dimensions**
- **Wafers mean thickness:**
  - **Multi – 168 μm ± 4.2 μm**
  - **Mono Cz – 173.1 μm ± 3.5 μm**
  - **Quasi-Mono – 168.1 μm ± 2.2 μm**
  - **Quasi-Mono (high defect density) – 168.5 μm ± 1.5 μm**









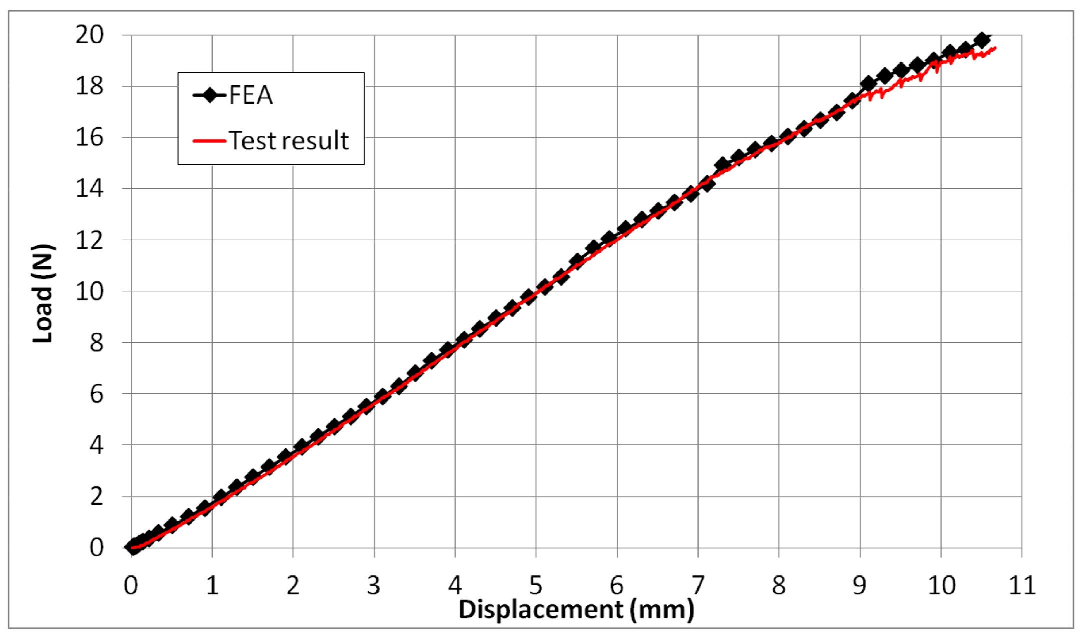


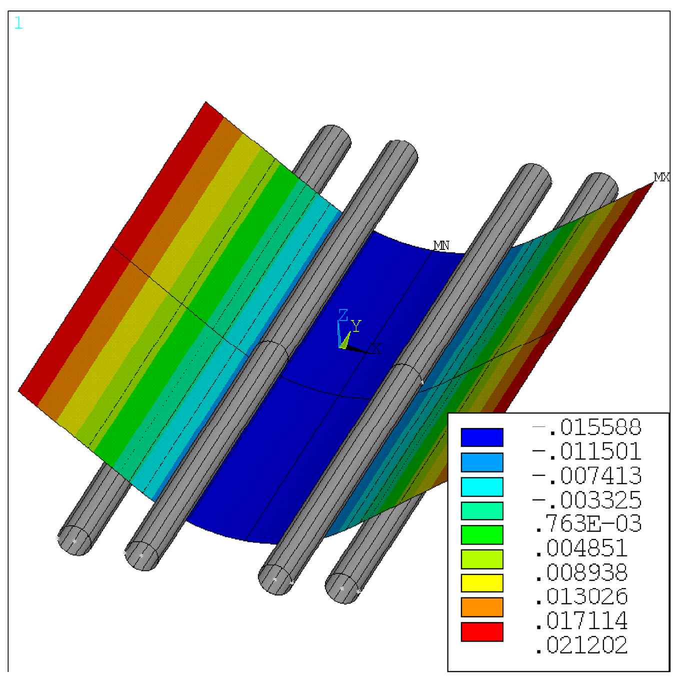
FE ANALYSIS

FE models simulating the tests taking into account the non linearities:

- **Contact between wafers and supports**
- **Large displacements**

In the case of monocrystalline wafers, anisotropic material properties have been used in the finite element simulations





Two FE models developed for each set: the corresponding to the thinnest and the thickest wafers.

CONCLUSIONS

- **The mechanical properties of 4 different types of crystalline silicon wafers, including the new quasi-mono substrates, have been for the first time compared using the Four Line Bending Test.**
- **The characteristic fracture tension values (according to the Weibull distribution) of multicrystalline, Cz-Si and low defect quasi-mono samples are comparable.**
- **Among the mono-like samples, quasi-mono wafers having high defect density showed the poorest mechanical performance. Interesting tension values were however still found.**

STATISTICAL EVALUATION

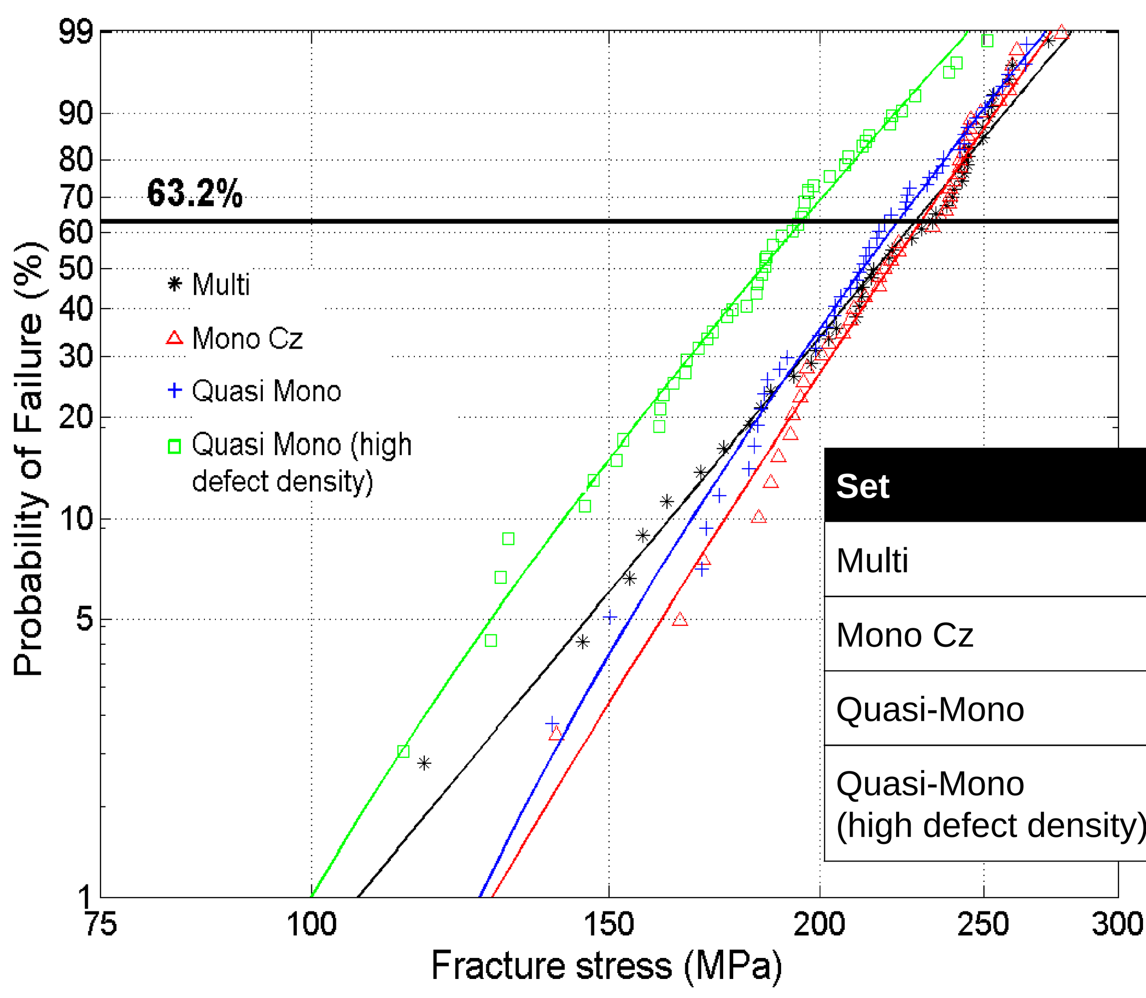
Three-parameter Weibull distribution (including size-effect):

$$P_{f,Aeq}(\sigma)=1-\exp\left[-\frac{Aeq}{\Delta A}\left(\frac{\sigma-\lambda}{\delta}\right)^{\beta}\right]$$

The equivalent area of each test (Aeq):

$$A_{eq}=\int_{dA\,\sigma>\lambda}\left(\frac{\sigma_i-\lambda}{\sigma_{\max}-\lambda}\right)^{\beta}dA$$

Through an iterative process:



λ – location parameter
δ - scale parameter
β - shape parameter
ΔA = uni-axially tensioned area = 4.e-3 m²

Set	λ (MPa)	δ (MPa)	β	σ_0 (MPa)
Multi	5.8e-5	228.21	6.84	228.21
Mono Cz	31.93	198.02	7.19	229.95
Quasi-Mono	69.07	153.78	5.22	222.85
Quasi-Mono (high defect density)	47.50	148.06	5.02	195.56

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